Chemical Quantities

The Mathematics of Chemical Equations

Stoichiometry

- Stoichiometry is the study of the quantitative relationships that exist in chemical formulas and chemical reactions
- Qualitative observations involve a verbal descriptions but not numbers
- Quantitative observations involve measurements and numbers

Chemical Equations

- Chemical equations give information about the relative numbers of substances that are involved in a chemical reaction
- The coefficients of a chemical equation tell how many atoms, molecules, or formula units of a substance are involved in the reaction

Chemical Equations

- Consider the following reaction: Propane gas (C_3H_8) burns in oxygen to produce carbon dioxide and water.
- Write the balanced equation for this reaction

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Chemical Equations

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

- This balanced equation tells us that 1 molecule of propane reacts with 5 molecules of oxygen to produce 3 molecules of carbon dioxide and 4 molecules of water
- However, we are very likely not going to have exactly those quantities

Chemical Equations

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

- For example: What if we had 2 molecules of propane?
- What if we had 10 molecules of propane?
- What if we had 100, or 1000, or 1,000,000 molecules of propane?
- What if we had 6.022×10^{23} molecules of propane?
- What if we had 12 moles of propane?

Mole Relationships

- So the balanced chemical equation not only gives us the ratio of atoms, molecules, or formula units but also the ratio of moles of atoms, molecules, or formula units
- But again, we may not have exactly 1 mole of propane. We may have 2 or 5 or 3.62 moles of propane

Mole Relationships

- What the balanced chemical equation gives us is a way to use the information about the number of moles of any of the reactants or products to find the number of moles of any of the other reactants or products
- The balanced chemical equation gives us a set of mole ratios

Mole Relationships

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

- For example: If 3.62 moles of propane are used in the reaction above, how many moles of oxygen are required?

$$3.62 \text{ moles } C_3H_8 \times \frac{5 \text{ moles } O_2}{1 \text{ mole } C_3H_8}$$

$$= 18.1 \text{ moles } O_2$$

Using Mole Ratios

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

- In the same reaction, how many moles of CO_2 are produced?

$$3.62 \text{ moles } C_3H_8 \times \frac{3 \text{ moles } CO_2}{1 \text{ mole } C_3H_8}$$

$$= 10.9 \text{ moles } CO_2$$

- How many moles of water would be produced?

$$3.62 \text{ moles } C_3H_8 \times \frac{4 \text{ moles } H_2O}{1 \text{ mole } C_3H_8}$$

$$= 14.5 \text{ moles } H_2O$$

Mole Relationships

- But it does not have to the first reactant that is given
- It could be another reactant or even a product that is given

Using Mole Ratios

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

- How many moles of CO_2 will be produced if .625 moles of O_2 are used in the reaction above?

  answer = .375 moles CO_2

- How many moles of H_2O would be produced if 1.72 moles of CO_2 are produced?

  answer = 2.29 moles H_2O

Using Mole Ratios

- Sample Problem: How many moles of hydrogen and oxygen gas are required to produce 13.2 moles of water?

Using Mole Ratios

- Write balanced equation

$$2H_2 + O_2 \rightarrow 2H_2O$$

- Use the mole ratios in the coefficients to determine the moles of H_2 and O_2

$$13.2 \text{ moles } H_2O \times \frac{2 \text{ moles } H_2}{2 \text{ moles } H_2O}$$

$$= 13.2 \text{ moles } H_2$$

$$13.2 \text{ moles } H_2O \times \frac{1 \text{ mole } O_2}{2 \text{ moles } H_2O}$$

$$= 6.60 \text{ moles } O_2$$

Mass Relationships

- Chemical reactions occur in ratios of moles
- However, we do not measure moles directly in the lab
- We usually measure chemical quantities using mass
- So a more realistic treatment of chemical quantities would also include mass-to-mole-to-mass conversions

Mass-Mass Problems

- For example: Iron reacts with copper (II) sulfate to produce copper and iron (III) sulfate. What mass of copper will be produced if 153 grams of iron is reacted with excess copper (II) sulfate?

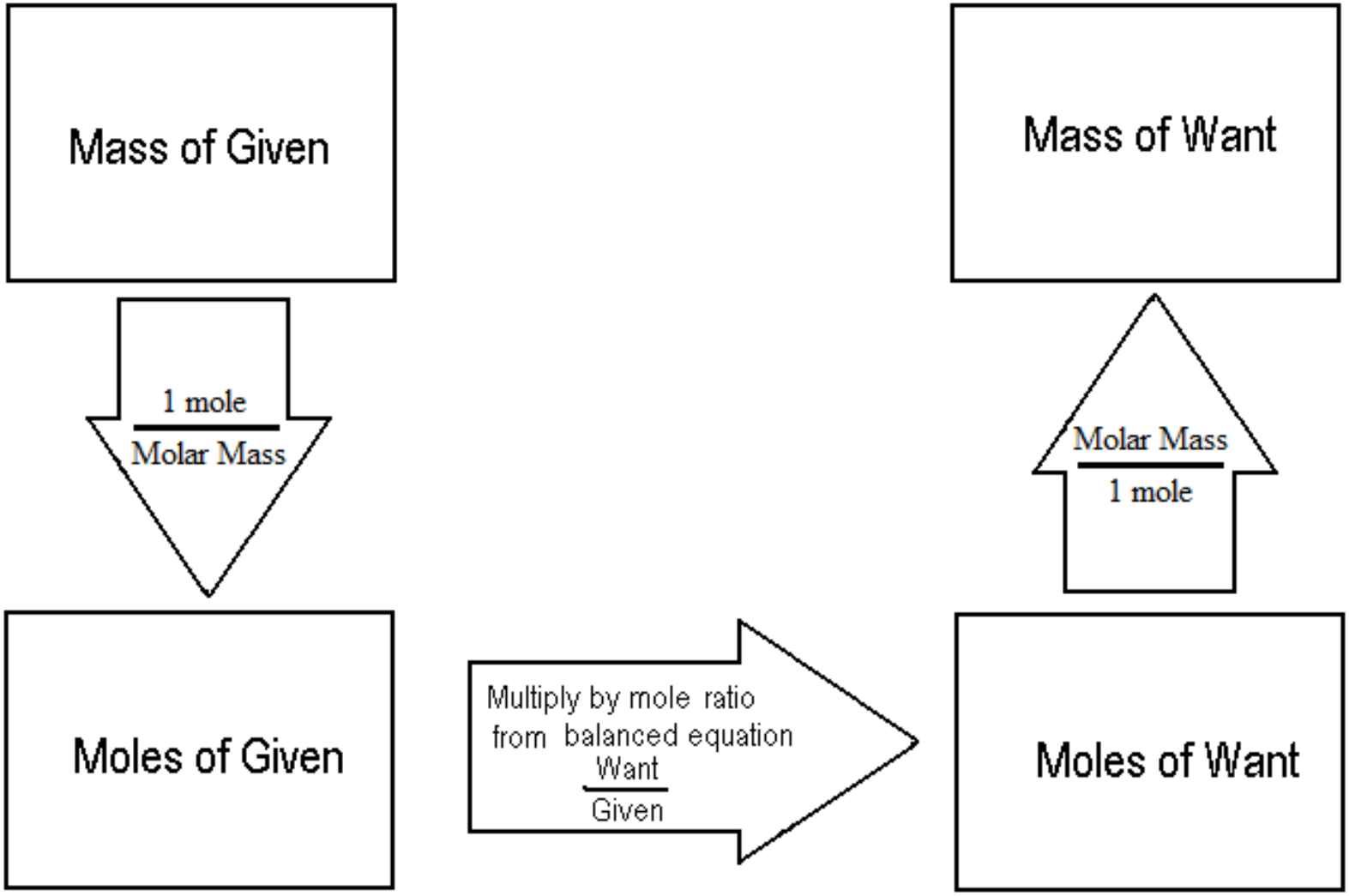
- What are the steps we need to follow to solve this problem?

Steps for Mass-Mass Problems

1. Write the balanced chemical equation
2. Convert mass of given substance to moles (divide by molar mass)
3. Multiply moles of given by mole ratio from chemical equation (want/given) to get moles of wanted substance
4. Convert moles of wanted substance to grams (multiply by molar mass)

Mass-Mass Problems

Start with balanced chemical equation



Mass-Mass Problems

Iron reacts with copper (II) sulfate to produce copper and iron (III) sulfate. What mass of copper will be produced if 153 grams of iron is reacted with excess copper (II) sulfate?

1. Write balanced chemical equation.

$$2Fe + 3CuSO_4 \rightarrow 3Cu + Fe_2(SO_4)_3$$

2. Convert mass of given to moles

$$\frac{153 \text{ g Fe}}{} \left| \frac{1 \text{ mole Fe}}{55.85 \text{ g Fe}} \right|$$

Mass-Mass Problems

$$2Fe + 3CuSO_4 \rightarrow 3Cu + Fe_2(SO_4)_3$$

3. Multiply moles of given by mole ratio from balanced chemical equation (want/given)

$$\frac{153 \text{ g Fe}}{} \left| \frac{1 \text{ mole Fe}}{55.85 \text{ g Fe}} \right| \frac{3 \text{ moles Cu}}{2 \text{ moles Fe}}$$

4. Convert moles of want to grams

$$\frac{153 \text{ g Fe}}{} \left| \frac{1 \text{ mole Fe}}{55.85 \text{ g Fe}} \right| \frac{3 \text{ moles Cu}}{2 \text{ moles Fe}} \left| \frac{63.55 \text{ g Cu}}{1 \text{ mole Cu}} \right| = 261 \text{ g Cu}$$

Mass-Mass Problems

What mass of chlorine is needed to react with excess phosphorus in order to produce 23.70 g of phosphorus trichloride in a synthesis reaction?

$$3Cl_2 + 2P \rightarrow 2PCl_3$$

23.70 g PCl_3	1 mole PCl_3	3 moles Cl_2	70.90 g Cl_2
	137.32 g PCl_3	2 moles PCl_3	1 mole Cl_2

= 18.35 g Cl_2